TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 403

# THE INTERFERENCE EFFECTS ON AN AIRFOIL OF A FLAT PLATE AT MID-SPAN POSITION

By Kenneth E. Ward

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Washington
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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE NO. 403

# THE INTERFERENCE EFFECTS ON AN AIRFOIL OF A FLAT PLATE AT MID-SPAN POSITION

By Kenneth E. Ward

## Summary

This report gives the results of an investigation of the mutual interference of an airfoil and a flat plate inserted at mid-span position. The tests were conducted in the Variable-Density Wind Tunnel of the National Advisory Committee for Aeronautics at a high value of the Reynolds Number. The interference effects of this combination were found to be small. Supplementary tests indicated that the use of fillets decreases both the lift and drag slightly. A bibliography of publications dealing with interference between wings and bodies, and with the effects of cut-outs and fillets is included.

## Introduction

The trend toward higher speeds in aircraft has made increasingly important the subject of mutual interference of airplane parts. A bibliography dealing with the interference between wings and bodies, and with the effects of cut-outs and fillets is included in this report for convenience of reference. Most of the information included in the bibliography, however, is unrelated and unsystematic and has been obtained from tests of models at low values of the Reynolds Number. Therefore, much of it is unsuitable for design use. The Variable-Density Wind Tunnel of the National Advisory Committee for Aeronautics affords a means of studying interference effects with models at large values of the Reynolds Number, the results of which may be compared directly to the effects which may be expected in the full-sized aircraft. A preliminary investigation of the interference effects of struts was recently made in this tunnel. (Reference 1.)

The first step in a progressive study of interference would be an investigation of the interference effects as shown upon basic forms at high values of the Reynolds Number. As a part of such an investigation, tests were conducted in the Variable-Density Wind Tunnel in June, 1931, upon a symmetrical airfoil having a flat plate inserted at mid-span position.

The interference effects were determined from tests of the airfoil and the interference plate, separately and in combination. Tests were also made with several sizes of fillets placed at the intersections between the plate and the airfoil surfaces to determine whether the use of fillets was effective in reducing adverse interference.

## Apparatus and Methods

The Variable-Density Wind Tunnel in which the present investigation was made is fully described in reference 2. Since this reference has been published, however, a number of important changes have been made to the tunnel which have been described in reference 3.

The airfoil used was a 5.75 by 36 inch duralumin model with a symmetrical section having a maximum thickness of 21 per cent, the N.A.C.A. 0021. (Reference 3.) The metal block from which the model was to be constructed was first cut at the mid-section to form two equal lengths, and an aluminum plate of the same thickness as the large interference plate was inserted between them. The two halves of the block and the small dummy plate were held securely together by means of a bolt and two dowel pins, as shown in Figure 1. The model was then shaped by means of a special airfoil-generating machine and finished to the desired dimensions as described in reference 3. By securing the three pieces together before cutting, a sharp, true profile of the airfoil was maintained at the point of intersection with the interference plate.

The interference model was constructed by replacing the dummy section in the airfoil by the interference plate. This model was varied by the addition of fillets for the purpose of investigating the effects produced. The fillets were made of plaster of Paris and were formed with thin metal templets having 3/8-inch, 3/4-inch and $1\frac{1}{2}$-inch radii, respectively. Figure 2 shows the airfoil-plate combination with fillets ready for testing in the tunnel.

For the purpose of testing the airfoil alone, the standard 3/16 by 5/8 inch sting was attached to the lower surface of the model on the dummy section. This was modified for a second test by replacing the standard sting and dummy section with a special sting constructed of a quarter-inch steel rod attached to a steel plate three-sixteenths inch thick conforming to the airfoil profile. This special sting eliminated the dissymmetry of the model caused by the standard form and also offered lower tare. The sting and the method of attachment of the component parts is shown in Figure 1.

The interference plate was constructed from a selected aluminum plate three-sixteenths inch thick. The general shape was that of a circular disk 18 inches in diameter, modified to accomodate a steel tail piece for the angle-of-attack mechanism and two steel side pieces for the purpose of supporting the plate horizontally between the balance-support struts. The edges of the plate were carefully streamlined and particular care was taken to make the plate flat and to keep the surfaces smooth. Holes to receive the bolt and dowels were accurately drilled to secure proper alignment and were so placed as to bring the leading edge of the airfoil 5 inches from the nose of the plate.

The tests were made at an average Reynolds Number of 3,600,000 which was obtained by using an air pressure in the tunnel of approximately 20 atmospheres. This value of the Reynolds Number corresponds approximately to the value reached by a medium-sized airplane when flying near minimum speed. The method of testing was essentially the same as that described in reference 2.

The airfoil and the interference plate were each tested under two different conditions of the model to determine the accuracy and variation of the test data with the conditions. The airfoil was first tested with the standard sting and the tares were computed by applying an area factor to the tares determined for the 5 by 30 inch models. A second test was made of the airfoil with the special sting described above and the tares were determined by measuring the forces on the supporting members with a dummy airfoil replacing the regular model, but mounted independently of the balance.

The interference plate was tested first in a horizontal position for the convenience of changing the angle of attack. It was run through angles of attack of 2° above and below the horizontal at 0.5° intervals to obtain the variation of drag with small angles and also to obtain the lowest drag value. The tares were determined by observing the forces on the supporting structure with the plate removed. A second test was made with the plate supported in a vertical position by a streamline-wire cage designed for minimum interference. The plate was carefully aligned to the position it occupied when in combination with the airfoil. The tares for this test were determined by observing the forces of the supporting members while the plate was in place but supported independently of the balance.

The airfoil and the plate were tested in four different combinations, first without fillets and then with three sizes of fillets. The tare forces were determined as before; a wooden airfoil in combination with the plate was used for the dummy model.

The test data have been corrected for air flow misalignment and for the change of position of the center of gravity of the model with change in the angle of attack.

## Precision

Because of the small values expected from the interference effects, particular care was taken to have all conditions as nearly alike as practicable for the different tests. The surface condition of the model was carefully inspected before each test. To determine the precision of the test data, the airfoil and the interference plate were each tested with two different conditions of the model, as mentioned above. The air flow misalignment was checked for each test by taking a number of points at negative angles of attack.

The difference in drag observed between the two tests of the plate alone was 5 per cent. The results of the test with the plate vertical are believed to be the more accurate of the two for the purpose of determining the interference effects because the plate was in the same position with respect to the tunnel that it occupied when in combination with the airfoil. The drag as determined by this test was therefore used for the final results. The drag value is believed to be correct within ±2 per cent.

The two tests of the airfoil alone differed by 5 per cent for the minimum drag and 2 per cent for the maximum lift. The results of the test of the airfoil supported by the special sting are believed to be the more accurate because of the symmetry of the model and the lower tare forces. Also, the tares for this condition were accurately determined by using a special dummy airfoil of the same shape and size as the model. The results of this test have therefore been used for the final results. The values of the minimum drag and the maximum lift for this test are each believed to be correct within ±2 per cent.

The airfoil-plate combinations were tested with the same degree of accuracy as the airfoil. The fillets were carefully cut to form with thin metal templets and the surfaces were finished by hand. The minimum-drag and maximum-lift values for these tests are each believed to be correct within ±2 per cent.

## Results and Discussion

The results of this investigation are presented in tabular and graphic form. In Tables I to V, inclusive are presented the values of the lift coefficient $C_L$, angle of attack corrected to infinite aspect ratio $\alpha_o$, profile-drag coefficient $C_{D_o}$, and moment coefficient about the quarter chord $C_{m_{c/4}}$. The corrected angle of attack and the profile-drag coefficient have been derived by the method of reference 4. Table VI compares the values of the minimum drag coefficients and maximum lift coefficients for the several conditions. This table also gives the percentage increase in minimum drag and the percentage decrease in maximum lift of the airfoil-plate combinations from the added values of the drag and lift of the airfoil tested alone and the interference plate tested alone.

The interference effects resulting from the plate in combination with the airfoil are indicated in Figure 3. A curve representing the drag of the plate plus the profile drag of the airfoil is compared in this figure with a curve representing the profile drag of the airfoil and plate in combination. These curves show that the interference effects increase the drag and decrease the lift.

The effects of fillets are shown graphically by comparative profile-drag curves in Figure 4, which indicate that fillets decrease both the drag and lift slightly. An increase in the size of the fillet increases the effect.

The results of these tests indicate that the interference effects resulting from a combination of an airfoil and a vertical plane surface at the mid-span are small.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 12, 1931.

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TABLE I

Airfoil: N.A.C.A. 0021
Airfoil Alone (Special Sting)

Average Reynolds Number: 3,600,000.

Size of model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.5.

Test No.: 622 Variable-Density Tunnel. June 13, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| 0.004 | 0.0 | 0.0119 | 0.001 |
| .153 | 1.6 | .0122 | .003 |
| .312 | 3.1 | .0126 | .006 |
| .615 | 6.2 | .0145 | .010 |
| .912 | 9.4 | .0182 | .010 |
| 1.188 | 12.6 | .0253 | .010 |
| 1.297 | 14.2 | .0334 | .008 |
| 1.333 | 15.1 | .0427 | .003 |
| 1.316 | 16.2 | .0688 | -.007 |

## TABLE II

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Without Fillets

Average Reynolds Number: 3,540,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.9.

Test No.: 615 Variable-Density Tunnel. May 21, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0208 | 0.000 |
| .072 | 0.8 | .0209 | .001 |
| .148 | 1.6 | .0210 | .003 |
| .297 | 3.1 | .0214 | .004 |
| .594 | 6.3 | .0234 | .008 |
| .883 | 9.4 | .0272 | .010 |
| 1.153 | 12.7 | .0347 | .010 |
| 1.262 | 14.3 | .0437 | .006 |
| 1.288 | 15.3 | .0571 | .001 |
| 1.275 | 16.3 | .0853 | -.009 |
| 1.251 | 18.4 | .1424 | -.031 |

TABLE III

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Small Fillets

Average Reynolds Number: 3,530,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 21.0.

Test No.: 618 Variable-Density Tunnel. June 4, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| 0.000 | 0.0 | 0.0207 | 0.000 |
| .148 | 1.6 | .0209 | .003 |
| .295 | 3.1 | .0213 | .005 |
| .591 | 6.3 | .0233 | .008 |
| .883 | 9.4 | .0267 | .010 |
| 1.147 | 12.7 | .0356 | .010 |
| 1.254 | 14.4 | .0469 | .004 |
| 1.273 | 15.3 | .0679 | -.004 |
| 1.253 | 16.4 | .0956 | -.015 |
| 1.208 | 18.5 | .1554 | -.034 |

TABLE IV

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Medium Fillets

Average Reynolds Number: 3,580,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.8.

Test No.: 616 Variable-Density Tunnel. May 22, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0205 | -0.001 |
| .074 | 0.8 | .0207 | .001 |
| .150 | 1.6 | .0210 | .002 |
| .299 | 3.1 | .0217 | .004 |
| .597 | 6.3 | .0234 | .007 |
| .887 | 9.4 | .0275 | .008 |
| 1.155 | 12.6 | .0368 | .005 |
| 1.265 | 14.3 | .0474 | .002 |
| 1.272 | 15.3 | .0674 | -.005 |
| 1.270 | 16.3 | .1005 | -.016 |
| 1.230 | 18.4 | .1588 | -.037 |

TABLE V

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Large Fillets

Average Reynolds Number: 3,550,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.7.

Test No.: 519 Variable-Density Tunnel. June 5, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0201 | 0.000 |
| .072 | 0.8 | .0203 | .001 |
| .148 | 1.6 | .0205 | .003 |
| .298 | 3.1 | .0209 | .004 |
| .598 | 6.3 | .0231 | .008 |
| .888 | 9.4 | .0270 | .010 |
| 1.156 | 12.6 | .0372 | .006 |
| 1.240 | 14.4 | .0610 | -.004 |
| 1.236 | 15.4 | .0905 | -.015 |
| 1.203 | 16.5 | .1253 | -.025 |
| 1.199 | 18.5 | .1747 | -.039 |

TABLE VI

Comparative Values of Minimum Drag and Maximum Lift

| Concept | $C_{D_o min}$ | $\Delta C_{D_o}$ | % inc. | $C_{L max}$ | $\Delta C_L$ | % dec. |
|---|---|---|---|---|---|---|
| Airfoil alone | 0.0119 | - | - | 1.333 | - | - |
| Plate alone | .0080 | - | - | - | - | - |
| Airfoil alone plus plate alone | .0199 | - | - | 1.333 | - | - |
| Airfoil with plate, without fillets | .0208 | 0.0009 | 4.5 | 1.288 | 0.045 | 3.4 |
| Airfoil with plate, small fillets | .0207 | .0008 | 4.0 | 1.273 | .060 | 4.5 |
| Airfoil with plate, medium fillets | .0205 | .0006 | 3.0 | 1.272 | .061 | 4.6 |
| Airfoil with plate, large fillets | .0201 | .0002 | 1.0 | 1.240 | .093 | 7.0 |

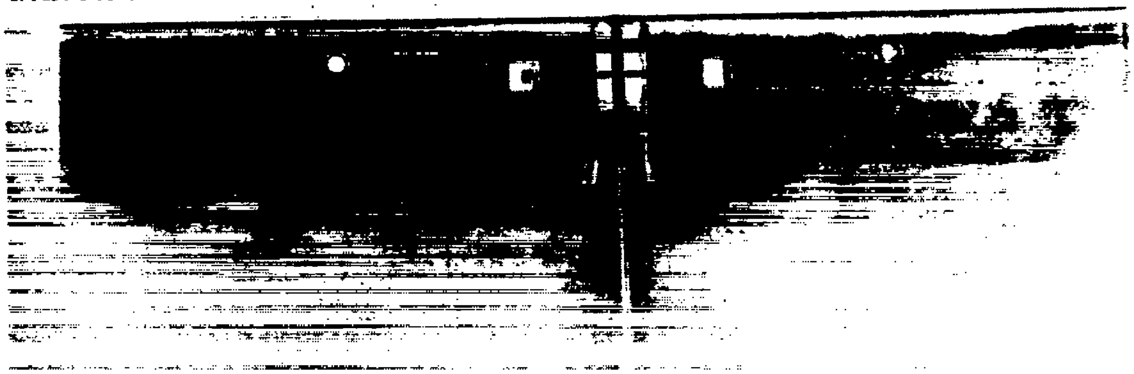
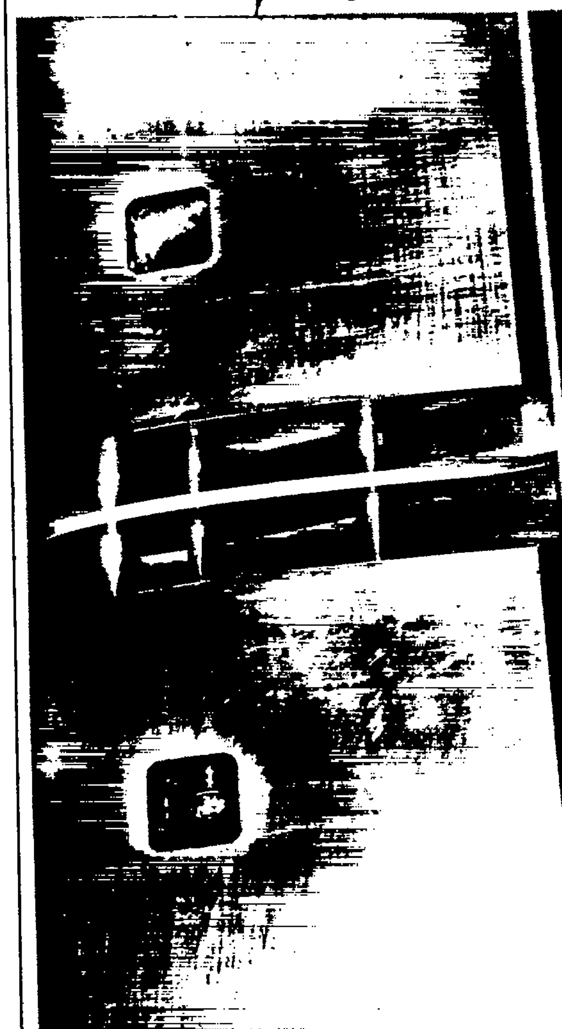


Fig.1 Airfoil with special sting showing method of securing component parts.



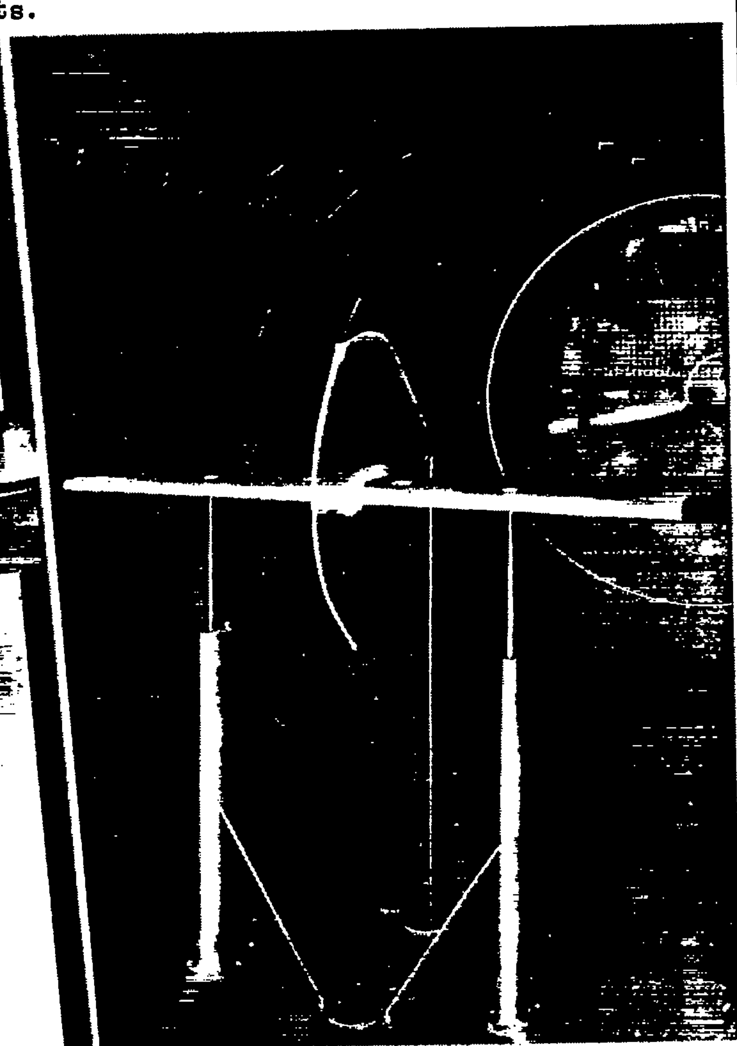


Fig.2 Airfoil-plate combination with fillets mounted in tunnel.

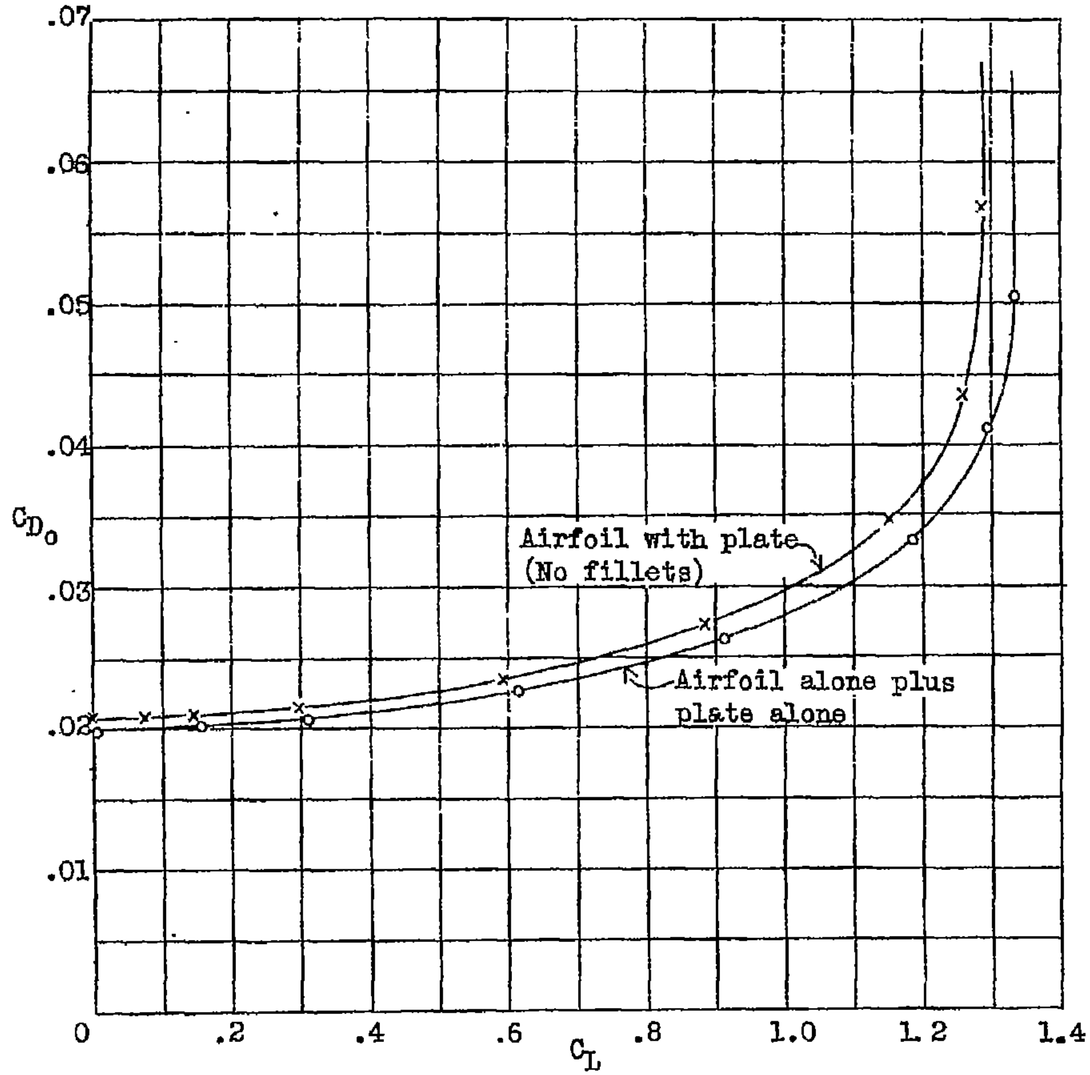



Fig.3 Airfoil-plate interference effects. Corrected to infinite aspect ratio. Average Reynolds Number = 3.6 X $10^6$ N.A.C.A. 0021

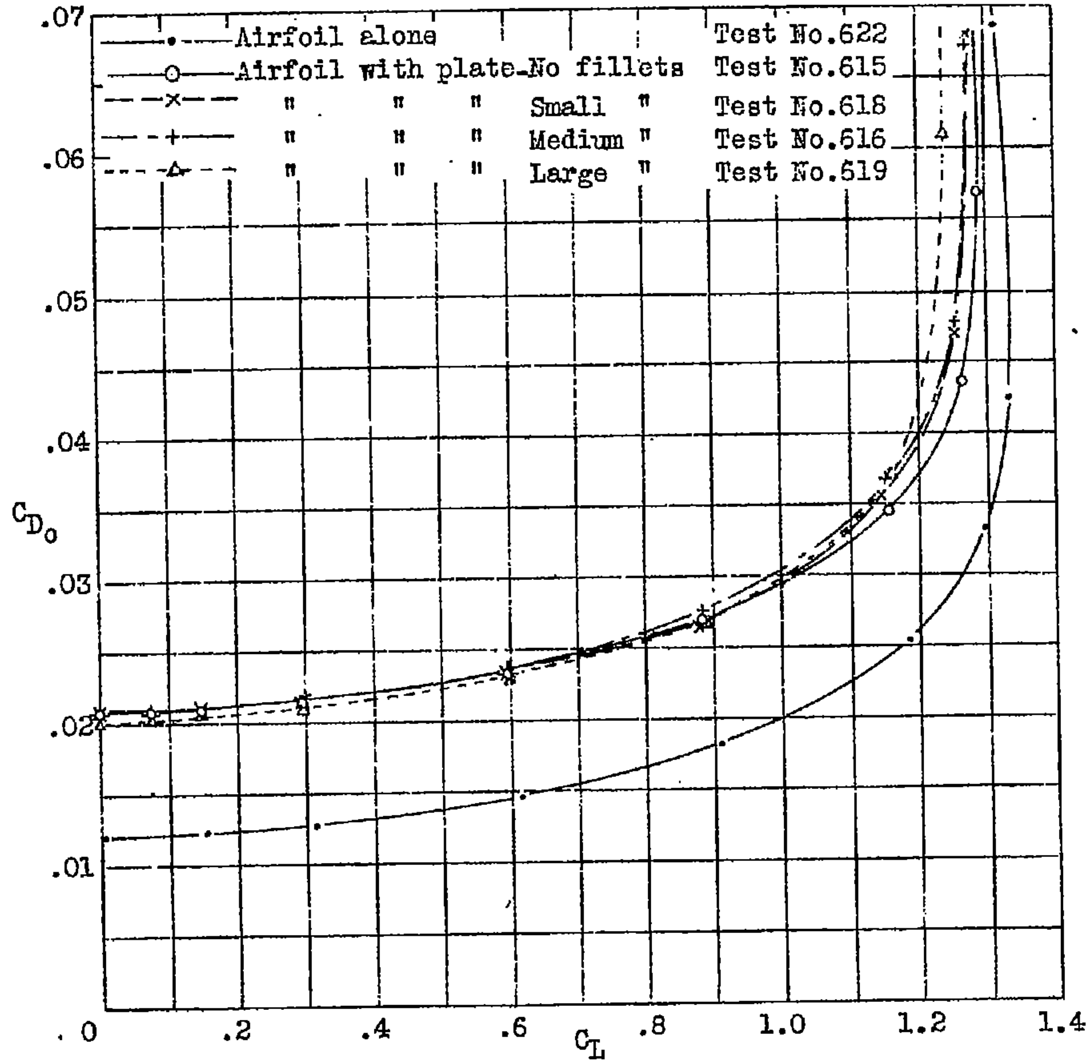



Fig.4 Airfoil-plate interference. Effect of fillets. Corrected to infinite aspect ratio. Average Reynolds Number = $3.6 \times 10^6$ N.A.C.A. 0021

TABLE V

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Large Fillets

Average Reynolds Number: 3,550,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.7.

Test No.: 519 Variable-Density Tunnel. June 5, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0201 | 0.000 |
| .072 | 0.8 | .0203 | .001 |
| .148 | 1.6 | .0205 | .003 |
| .298 | 3.1 | .0209 | .004 |
| .598 | 6.3 | .0231 | .008 |
| .888 | 9.4 | .0270 | .010 |
| 1.156 | 12.6 | .0372 | .006 |
| 1.240 | 14.4 | .0610 | -.004 |
| 1.236 | 15.4 | .0905 | -.015 |
| 1.203 | 16.5 | .1253 | -.025 |
| 1.199 | 18.5 | .1747 | -.039 |

TABLE VI

Comparative Values of Minimum Drag and Maximum Lift

| Concept | $C_{D_o min}$ | $\Delta C_{D_o}$ | % inc. | $C_{L max}$ | $\Delta C_L$ | % dec. |
|---|---|---|---|---|---|---|
| Airfoil alone | 0.0119 | - | - | 1.333 | - | - |
| Plate alone | .0080 | - | - | - | - | - |
| Airfoil alone plus plate alone | .0199 | - | - | 1.333 | - | - |
| Airfoil with plate, without fillets | .0208 | 0.0009 | 4.5 | 1.288 | 0.045 | 3.4 |
| Airfoil with plate, small fillets | .0207 | .0008 | 4.0 | 1.273 | .060 | 4.5 |
| Airfoil with plate, medium fillets | .0205 | .0006 | 3.0 | 1.272 | .061 | 4.6 |
| Airfoil with plate, large fillets | .0201 | .0002 | 1.0 | 1.240 | .093 | 7.0 |

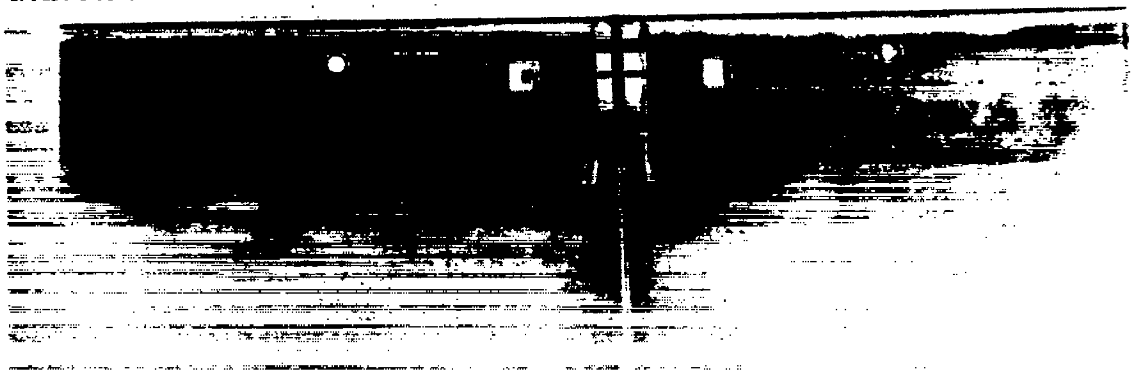


Fig.1 Airfoil with special sting showing method of securing component parts.

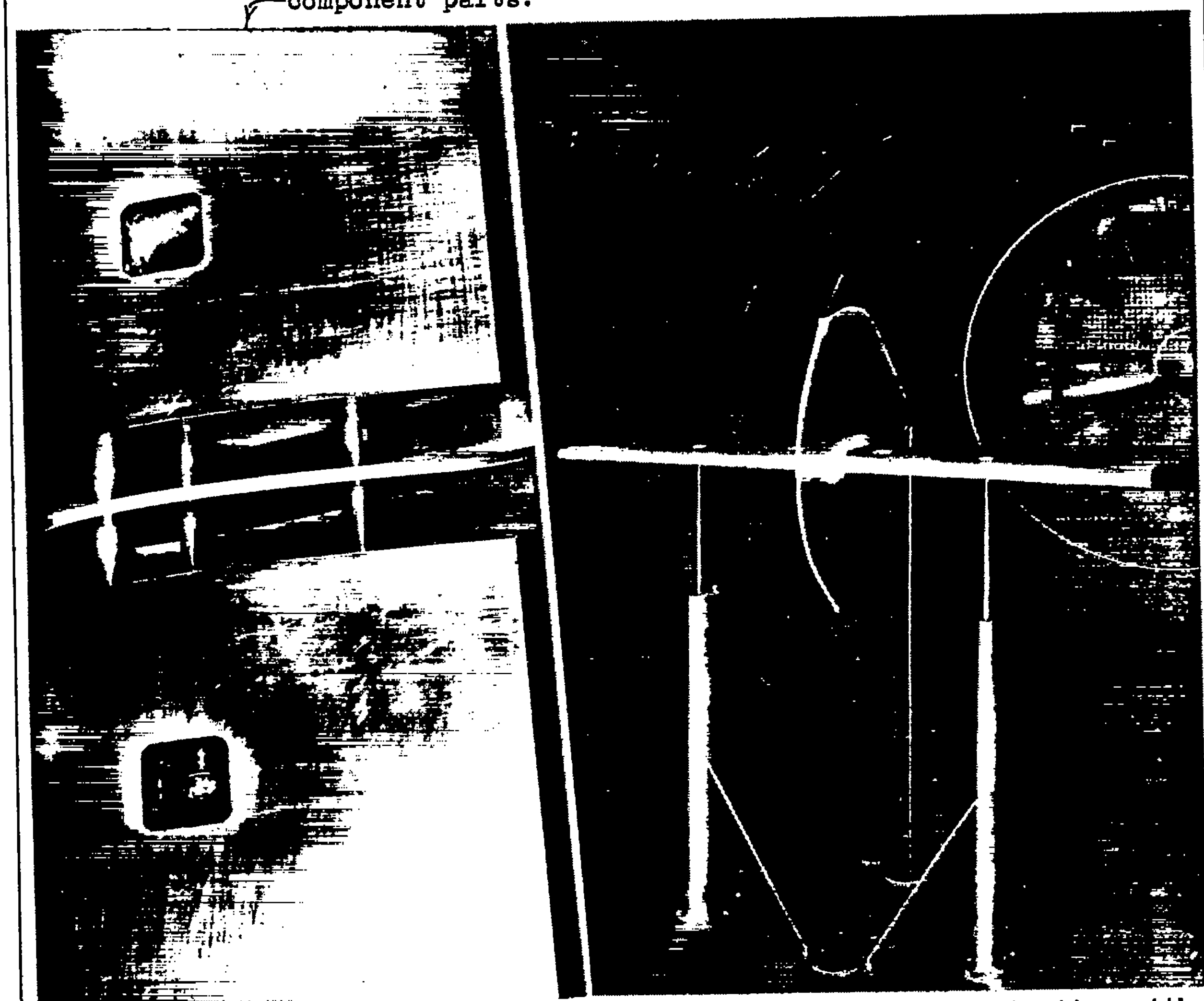


Fig.2 Airfoil-plate combination with fillets mounted in tunnel.

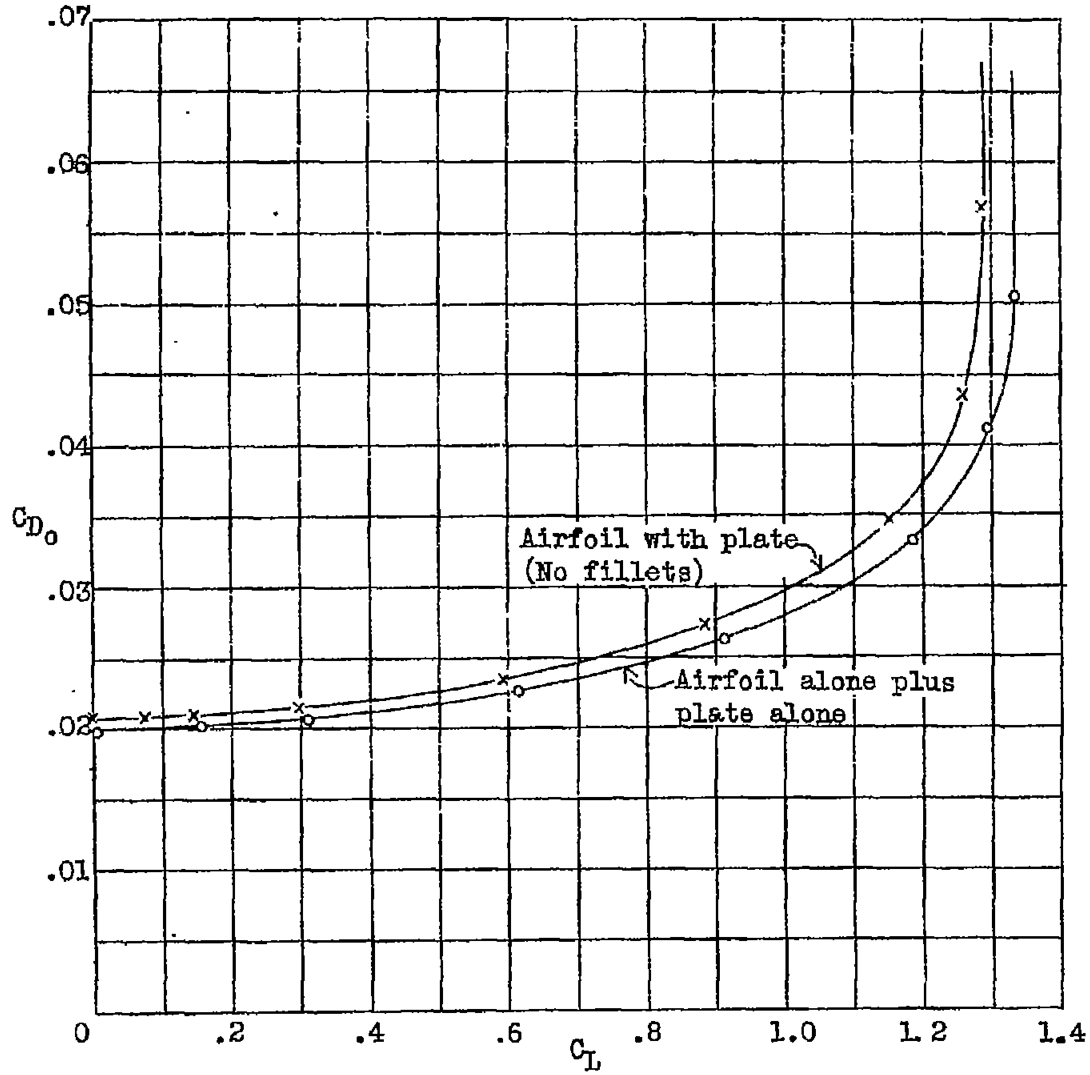
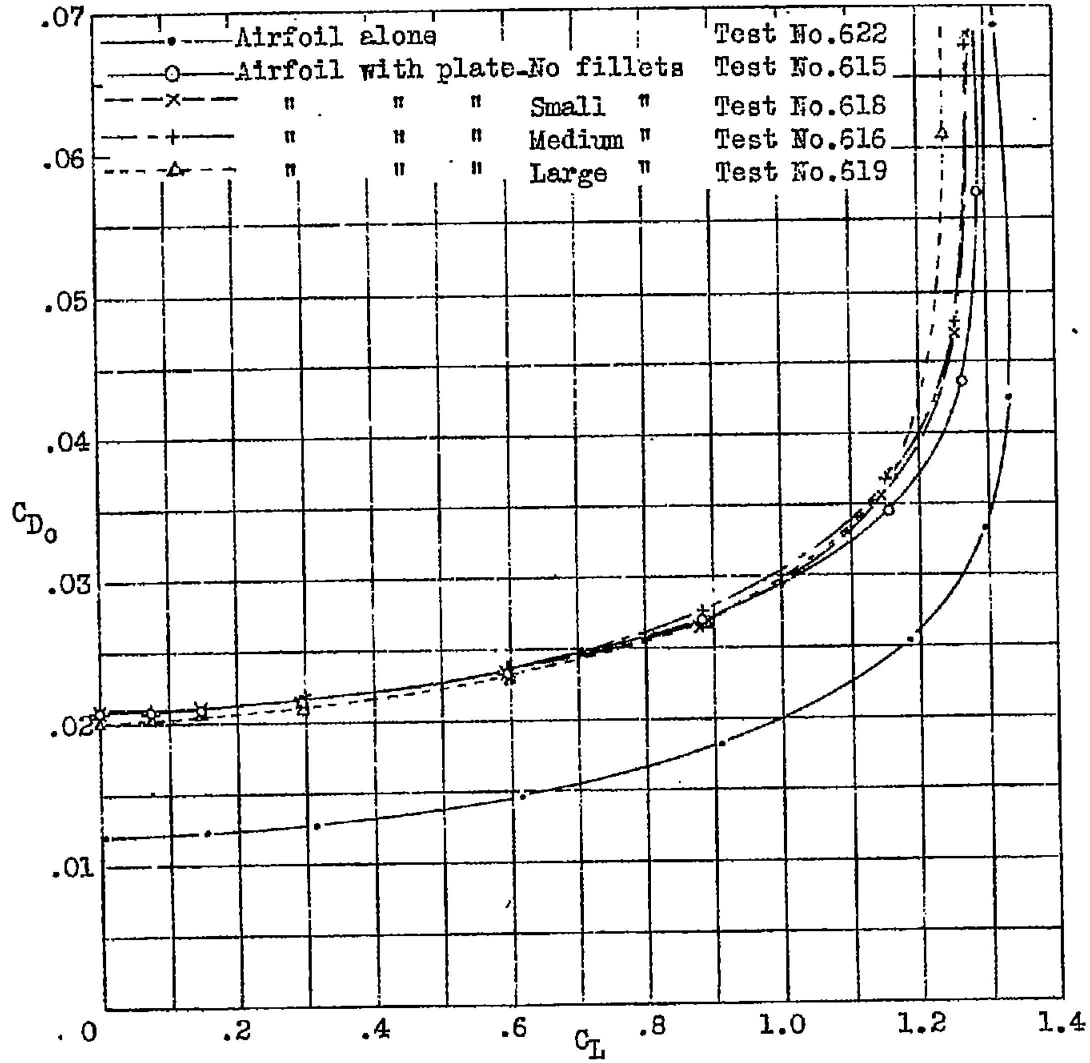



Fig.3 Airfoil-plate interference effects. Corrected to infinite aspect ratio. Average Reynolds Number = $3.6 \times 10^6$ N.A.C.A. 0021




(max)
5.7 % loss in lift due to flat plate

Fig.4 Airfoil-plate interference. Effect of fillets. Corrected to infinite aspect ratio.
Average Reynolds Number = $3.6 \times 10^6$ N.A.C.A. 0021

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This report gives the results of an investigation of the mutual interference of an airfoil and a flat plate inserted at mid-span position. The tests were conducted in the Variable-Density Wind Tunnel of the National Advisory Committee for Aeronautics at a high value of the Reynolds Number. The interference effects of this combination were found to be small. Supplementary tests indicated that the use of fillets decreases both the lift and drag slightly. A bibliography of publications dealing with interference between wings and bodies, and with the effects of cut-outs and fillets is included.

## Introduction

The trend toward higher speeds in aircraft has made increasingly important the subject of mutual interference of airplane parts. A bibliography dealing with the interference between wings and bodies, and with the effects of cut-outs and fillets is included in this report for convenience of reference. Most of the information included in the bibliography, however, is unrelated and unsystematic and has been obtained from tests of models at low values of the Reynolds Number. Therefore, much of it is unsuitable for design use. The Variable-Density Wind Tunnel of the National Advisory Committee for Aeronautics affords a means of studying interference effects with models at large values of the Reynolds Number, the results of which may be compared directly to the effects which may be expected in the full-sized aircraft. A preliminary investigation of the interference effects of struts was recently made in this tunnel. (Reference 1.)

The first step in a progressive study of interference would be an investigation of the interference effects as shown upon basic forms at high values of the Reynolds Number. As a part of such an investigation, tests were conducted in the Variable-Density Wind Tunnel in June, 1931, upon a symmetrical airfoil having a flat plate inserted at mid-span position.

The interference effects were determined from tests of the airfoil and the interference plate, separately and in combination. Tests were also made with several sizes of fillets placed at the intersections between the plate and the airfoil surfaces to determine whether the use of fillets was effective in reducing adverse interference.

## Apparatus and Methods

The Variable-Density Wind Tunnel in which the present investigation was made is fully described in reference 2. Since this reference has been published, however, a number of important changes have been made to the tunnel which have been described in reference 3.

The airfoil used was a 5.75 by 36 inch duralumin model with a symmetrical section having a maximum thickness of 21 per cent, the N.A.C.A. 0021. (Reference 3.) The metal block from which the model was to be constructed was first cut at the mid-section to form two equal lengths, and an aluminum plate of the same thickness as the large interference plate was inserted between them. The two halves of the block and the small dummy plate were held securely together by means of a bolt and two dowel pins, as shown in Figure 1. The model was then shaped by means of a special airfoil-generating machine and finished to the desired dimensions as described in reference 3. By securing the three pieces together before cutting, a sharp, true profile of the airfoil was maintained at the point of intersection with the interference plate.

The interference model was constructed by replacing the dummy section in the airfoil by the interference plate. This model was varied by the addition of fillets for the purpose of investigating the effects produced. The fillets were made of plaster of Paris and were formed with thin metal templets having 3/8-inch, 3/4-inch and $1\frac{1}{2}$-inch radii, respectively. Figure 2 shows the airfoil-plate combination with fillets ready for testing in the tunnel.

For the purpose of testing the airfoil alone, the standard 3/16 by 5/8 inch sting was attached to the lower surface of the model on the dummy section. This was modified for a second test by replacing the standard sting and dummy section with a special sting constructed of a quarter-inch steel rod attached to a steel plate three-sixteenths inch thick conforming to the airfoil profile. This special sting eliminated the dissymmetry of the model caused by the standard form and also offered lower tare. The sting and the method of attachment of the component parts is shown in Figure 1.

The interference plate was constructed from a selected aluminum plate three-sixteenths inch thick. The general shape was that of a circular disk 18 inches in diameter, modified to accomodate a steel tail piece for the angle-of-attack mechanism and two steel side pieces for the purpose of supporting the plate horizontally between the balance-support struts. The edges of the plate were carefully streamlined and particular care was taken to make the plate flat and to keep the surfaces smooth. Holes to receive the bolt and dowels were accurately drilled to secure proper alignment and were so placed as to bring the leading edge of the airfoil 5 inches from the nose of the plate.

The tests were made at an average Reynolds Number of 3,600,000 which was obtained by using an air pressure in the tunnel of approximately 20 atmospheres. This value of the Reynolds Number corresponds approximately to the value reached by a medium-sized airplane when flying near minimum speed. The method of testing was essentially the same as that described in reference 2.

The airfoil and the interference plate were each tested under two different conditions of the model to determine the accuracy and variation of the test data with the conditions. The airfoil was first tested with the standard sting and the tares were computed by applying an area factor to the tares determined for the 5 by 30 inch models. A second test was made of the airfoil with the special sting described above and the tares were determined by measuring the forces on the supporting members with a dummy airfoil replacing the regular model, but mounted independently of the balance.

The interference plate was tested first in a horizontal position for the convenience of changing the angle of attack. It was run through angles of attack of 2° above and below the horizontal at 0.5° intervals to obtain the variation of drag with small angles and also to obtain the lowest drag value. The tares were determined by observing the forces on the supporting structure with the plate removed. A second test was made with the plate supported in a vertical position by a streamline-wire cage designed for minimum interference. The plate was carefully aligned to the position it occupied when in combination with the airfoil. The tares for this test were determined by observing the forces of the supporting members while the plate was in place but supported independently of the balance.

The airfoil and the plate were tested in four different combinations, first without fillets and then with three sizes of fillets. The tare forces were determined as before; a wooden airfoil in combination with the plate was used for the dummy model.

The test data have been corrected for air flow misalignment and for the change of position of the center of gravity of the model with change in the angle of attack.

## Precision

Because of the small values expected from the interference effects, particular care was taken to have all conditions as nearly alike as practicable for the different tests. The surface condition of the model was carefully inspected before each test. To determine the precision of the test data, the airfoil and the interference plate were each tested with two different conditions of the model, as mentioned above. The air flow misalignment was checked for each test by taking a number of points at negative angles of attack.

The difference in drag observed between the two tests of the plate alone was 5 per cent. The results of the test with the plate vertical are believed to be the more accurate of the two for the purpose of determining the interference effects because the plate was in the same position with respect to the tunnel that it occupied when in combination with the airfoil. The drag as determined by this test was therefore used for the final results. The drag value is believed to be correct within ±2 per cent.

The two tests of the airfoil alone differed by 5 per cent for the minimum drag and 2 per cent for the maximum lift. The results of the test of the airfoil supported by the special sting are believed to be the more accurate because of the symmetry of the model and the lower tare forces. Also, the tares for this condition were accurately determined by using a special dummy airfoil of the same shape and size as the model. The results of this test have therefore been used for the final results. The values of the minimum drag and the maximum lift for this test are each believed to be correct within ±2 per cent.

The airfoil-plate combinations were tested with the same degree of accuracy as the airfoil. The fillets were carefully cut to form with thin metal templets and the surfaces were finished by hand. The minimum-drag and maximum-lift values for these tests are each believed to be correct within ±2 per cent.

## Results and Discussion

The results of this investigation are presented in tabular and graphic form. In Tables I to V, inclusive are presented the values of the lift coefficient $C_L$, angle of attack corrected to infinite aspect ratio $\alpha_o$, profile-drag coefficient $C_{D_o}$, and moment coefficient about the quarter chord $C_{m_{c/4}}$. The corrected angle of attack and the profile-drag coefficient have been derived by the method of reference 4. Table VI compares the values of the minimum drag coefficients and maximum lift coefficients for the several conditions. This table also gives the percentage increase in minimum drag and the percentage decrease in maximum lift of the airfoil-plate combinations from the added values of the drag and lift of the airfoil tested alone and the interference plate tested alone.

The interference effects resulting from the plate in combination with the airfoil are indicated in Figure 3. A curve representing the drag of the plate plus the profile drag of the airfoil is compared in this figure with a curve representing the profile drag of the airfoil and plate in combination. These curves show that the interference effects increase the drag and decrease the lift.

The effects of fillets are shown graphically by comparative profile-drag curves in Figure 4, which indicate that fillets decrease both the drag and lift slightly. An increase in the size of the fillet increases the effect.

The results of these tests indicate that the interference effects resulting from a combination of an airfoil and a vertical plane surface at the mid-span are small.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 12, 1931.

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TABLE I

Airfoil: N.A.C.A. 0021
Airfoil Alone (Special Sting)

Average Reynolds Number: 3,600,000.

Size of model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.5.

Test No.: 622 Variable-Density Tunnel. June 13, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| 0.004 | 0.0 | 0.0119 | 0.001 |
| .153 | 1.6 | .0122 | .003 |
| .312 | 3.1 | .0126 | .006 |
| .615 | 6.2 | .0145 | .010 |
| .912 | 9.4 | .0182 | .010 |
| 1.188 | 12.6 | .0253 | .010 |
| 1.297 | 14.2 | .0334 | .008 |
| 1.333 | 15.1 | .0427 | .003 |
| 1.316 | 16.2 | .0688 | -.007 |

TABLE II

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Without Fillets

Average Reynolds Number: 3,540,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.9.

Test No.: 615 Variable-Density Tunnel. May 21, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0208 | 0.000 |
| .072 | 0.8 | .0209 | .001 |
| .148 | 1.6 | .0210 | .003 |
| .297 | 3.1 | .0214 | .004 |
| .594 | 6.3 | .0234 | .008 |
| .883 | 9.4 | .0272 | .010 |
| 1.153 | 12.7 | .0347 | .010 |
| 1.262 | 14.3 | .0437 | .006 |
| 1.288 | 15.3 | .0571 | .001 |
| 1.275 | 16.3 | .0853 | -.009 |
| 1.251 | 18.4 | .1424 | -.031 |

TABLE III

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Small Fillets

Average Reynolds Number: 3,530,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 21.0.

Test No.: 618 Variable-Density Tunnel. June 4, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| 0.000 | 0.0 | 0.0207 | 0.000 |
| .148 | 1.6 | .0209 | .003 |
| .295 | 3.1 | .0213 | .005 |
| .591 | 6.3 | .0233 | .008 |
| .883 | 9.4 | .0267 | .010 |
| 1.147 | 12.7 | .0356 | .010 |
| 1.254 | 14.4 | .0469 | .004 |
| 1.273 | 15.3 | .0679 | -.004 |
| 1.253 | 16.4 | .0956 | -.015 |
| 1.208 | 18.5 | .1554 | -.034 |

TABLE IV

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Medium Fillets

Average Reynolds Number: 3,580,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.8.

Test No.: 616 Variable-Density Tunnel. May 22, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0205 | -0.001 |
| .074 | 0.8 | .0207 | .001 |
| .150 | 1.6 | .0210 | .002 |
| .299 | 3.1 | .0217 | .004 |
| .597 | 6.3 | .0234 | .007 |
| .887 | 9.4 | .0275 | .008 |
| 1.155 | 12.6 | .0368 | .005 |
| 1.265 | 14.3 | .0474 | .002 |
| 1.272 | 15.3 | .0674 | -.005 |
| 1.270 | 16.3 | .1005 | -.016 |
| 1.230 | 18.4 | .1588 | -.037 |

TABLE V

Airfoil: N.A.C.A. 0021
Airfoil with Plate - Large Fillets

Average Reynolds Number: 3,550,000.

Size of Model: 5.75 by 36 inches.

Pressure, Standard Atmospheres: 20.7.

Test No.: 519 Variable-Density Tunnel. June 5, 1931.

| $C_L$ | $\alpha_o$ (degrees) | $C_{D_o}$ | $C_{m_{c/4}}$ |
|---|---|---|---|
| -0.002 | 0.0 | 0.0201 | 0.000 |
| .072 | 0.8 | .0203 | .001 |
| .148 | 1.6 | .0205 | .003 |
| .298 | 3.1 | .0209 | .004 |
| .598 | 6.3 | .0231 | .008 |
| .888 | 9.4 | .0270 | .010 |
| 1.156 | 12.6 | .0372 | .006 |
| 1.240 | 14.4 | .0610 | -.004 |
| 1.236 | 15.4 | .0905 | -.015 |
| 1.203 | 16.5 | .1253 | -.025 |
| 1.199 | 18.5 | .1747 | -.039 |

TABLE VI

Comparative Values of Minimum Drag and Maximum Lift

| Concept | $C_{D_o min}$ | $\Delta C_{D_o}$ | % inc. | $C_{L max}$ | $\Delta C_L$ | % dec. |
|---|---|---|---|---|---|---|
| Airfoil alone | 0.0119 | - | - | 1.333 | - | - |
| Plate alone | .0080 | - | - | - | - | - |
| Airfoil alone plus plate alone | .0199 | - | - | 1.333 | - | - |
| Airfoil with plate, without fillets | .0208 | 0.0009 | 4.5 | 1.288 | 0.045 | 3.4 |
| Airfoil with plate, small fillets | .0207 | .0008 | 4.0 | 1.273 | .060 | 4.5 |
| Airfoil with plate, medium fillets | .0205 | .0006 | 3.0 | 1.272 | .061 | 4.6 |
| Airfoil with plate, large fillets | .0201 | .0002 | 1.0 | 1.240 | .093 | 7.0 |

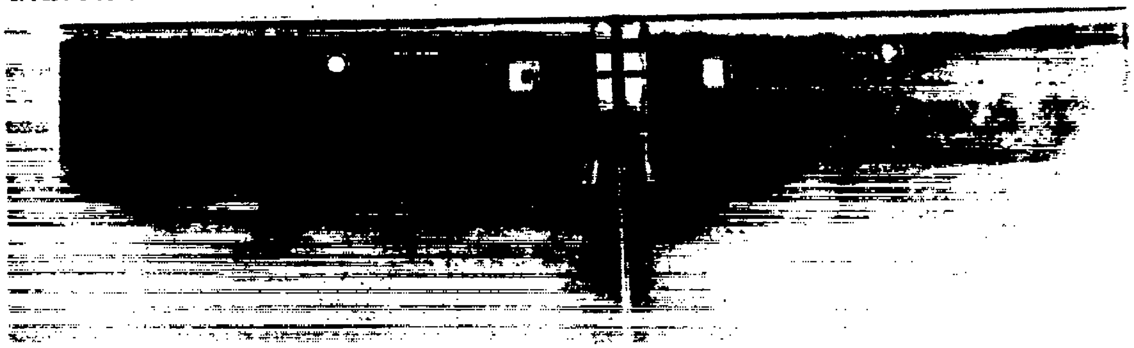
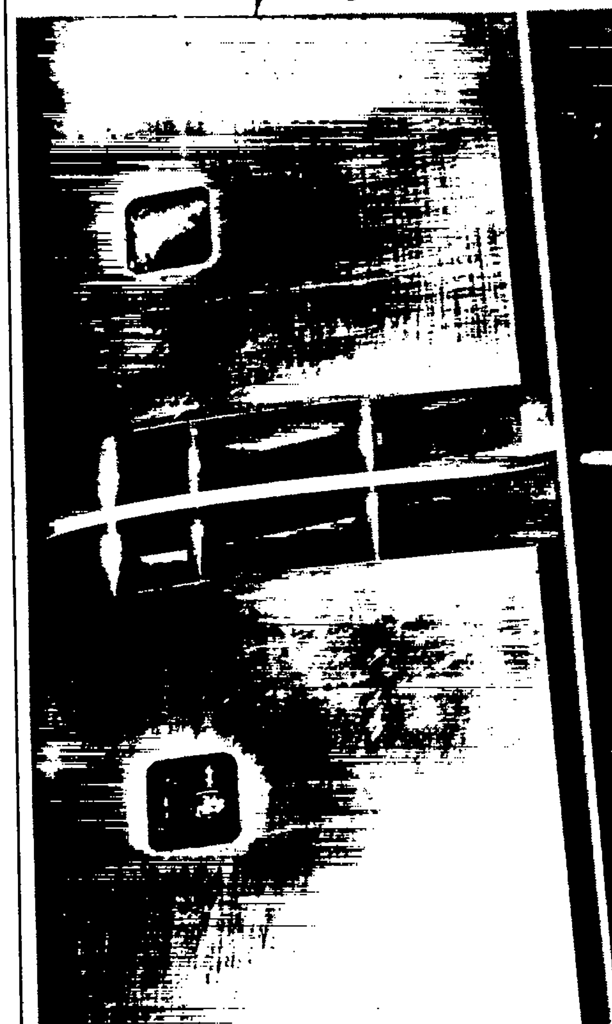


Fig.1 Airfoil with special sting showing method of securing component parts.



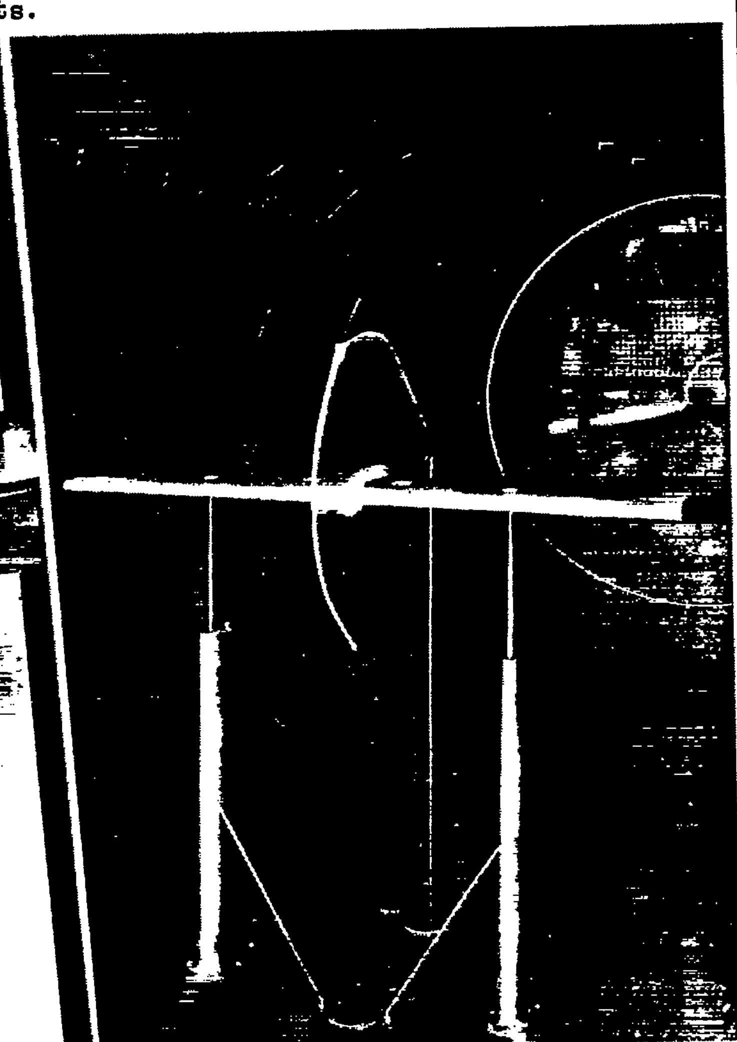


Fig.2 Airfoil-plate combination with fillets mounted in tunnel.

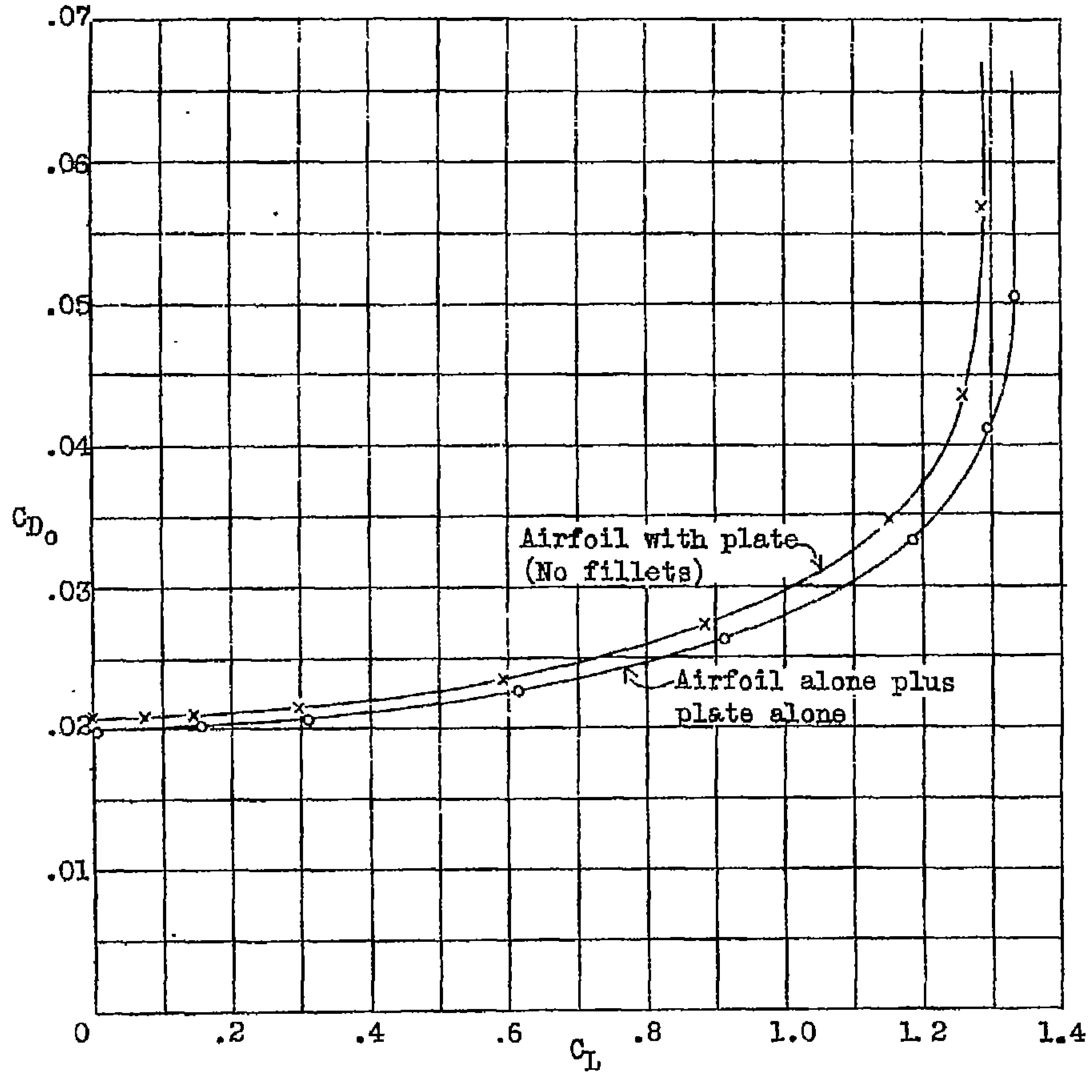
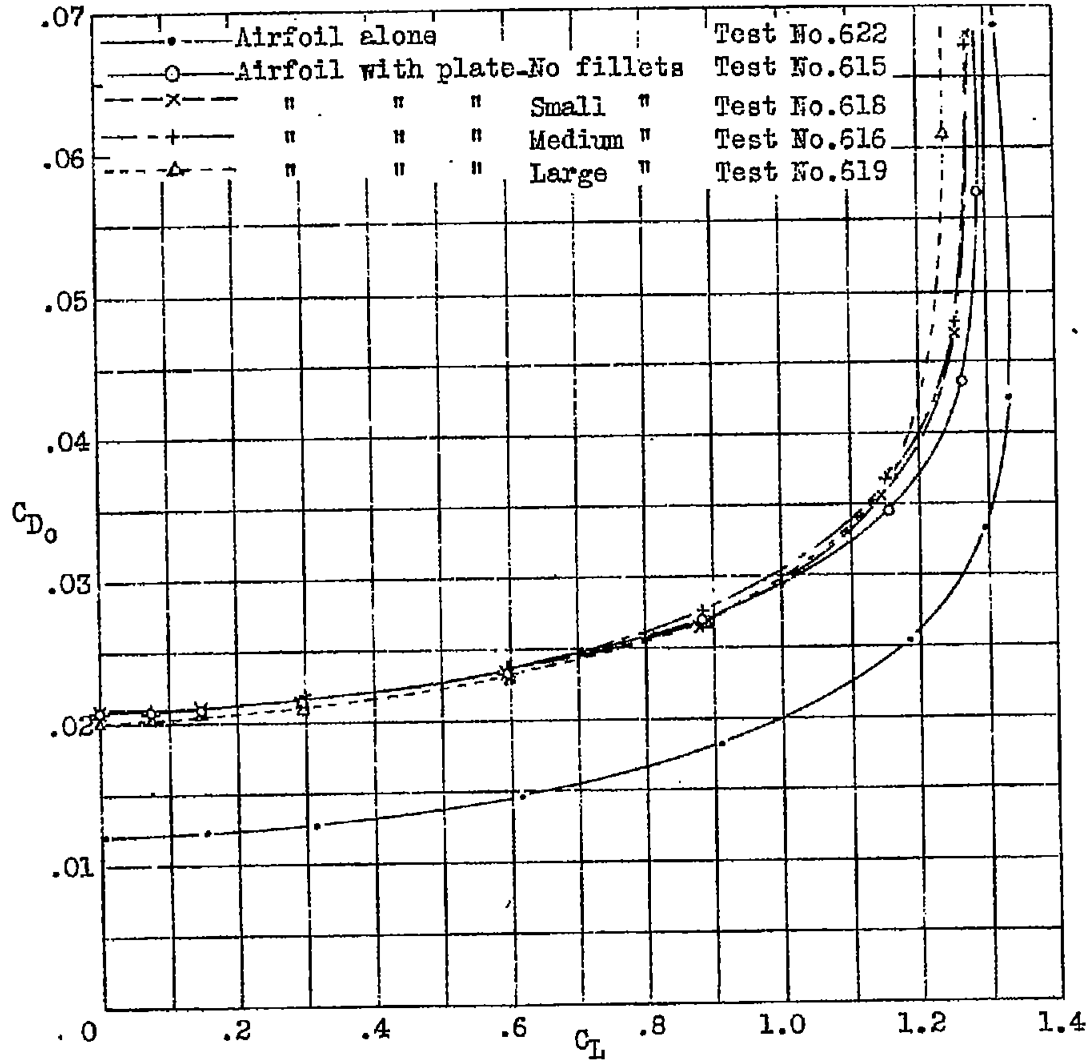



Fig.3 Airfoil-plate interference effects. Corrected to infinite aspect ratio. Average Reynolds Number = $3.6 \times 10^6$ N.A.C.A. 0021




(Max) 5.7 % loss in lift due to flat plate

Fig.4 Airfoil-plate interference. Effect of fillets. Corrected to infinite aspect ratio.
Average Reynolds Number = $3.6 \times 10^6$ N.A.C.A. 0021